

**APPARATUS AND METHOD FOR ADAPTIVELY CONTROLLING POWER
SUPPLIED TO A HOT-PLUGGABLE SUBSYSTEM**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to power supplies, and more specifically to a method and apparatus for adaptively controlling power supplied to a hot-pluggable subsystem.

2. Background of the Invention

Computers and other electronic systems such as telecom systems require replacement and/or addition of subsystems without removing power from a host system. Known as "hot-pluggable" subsystems, these electrical devices must operate properly after connection and disconnection, while not disrupting the operation of other electronic circuits. Telecom systems typically operate at a much higher voltage (-48V) and telecom subsystems typically have high current drains due to the low-impedance nature of telephony circuits. Thus, the input capacitances required to filter EMI and conducted ripple on the input of telecom subsystems are typically large and a hot-

pluggable subsystem for telecom generally requires sophisticated inrush current protection.

Additionally, peripheral devices, storage devices and redundant processor modules in both network server systems and personal computing systems can be removed or attached while the systems remain active. Network connections between systems must also support active connection and disconnection, since the entire network should not be shut down to add or remove computers or other devices. Power to connected sub-systems may be supplied through network interface cables. For example, the Powered Ethernet Specification 802.3 promulgated by the Institute of Electrical and Electronic Engineers (IEEE), specifies an interface wherein power is supplied through the network cable connection. Hot-pluggable network hubs, network telecom cards including fiber optic interfaces, transceivers and cards for analog telephonic interfaces may all be powered by a host system.

Inrush current must be managed in hot-plugging systems, as the transients generated when the hot-pluggable subsystem is connected to the host system can damage connectors, cause dips in the power supply rails and generate electromagnetic

interference (EMI) that affect the operation of the host system and other connected subsystems.

Power supplies for hot-pluggable subsystems having a minimum of electrical connections and incorporated within small integrated circuit packages are very desirable. In general it is useful to provide power supply integrated circuits requiring a minimum of circuit area and external connections. Generally, an external pass element is used with an integrated circuit controller so that the controller may be used in many different applications with the pass element sized appropriately for the current and voltage requirements of a particular application. As the size and the equivalent input capacitance of the pass element used is not known *a priori*, therefore it would be desirable to compensate for differences in the size of the pass element in order to normalize turn on time and other characteristics without requiring external components specifically chosen for a given pass element.

Power supplies for a hot-pluggable subsystem are typically required to provide a stable time period in which the power supply voltage applied to the hot-pluggable device does not vary while the hot-pluggable device initializes. This presents difficulty in that mechanical contact bounce may electrically

connect and disconnect the power supply conductors several times before the device is properly coupled. A de-bounce time interval and/or a power-on-reset (POR) time interval are typically provided to prevent improperly initializing a hot-pluggable subsystem, but implementation of the de-bounce and power-on-reset time intervals typically requires additional components, adding to size, complexity and cost of power supply electronics.

Other features desirable in a power supply for coupling to a hot-pluggable sub-system are short-circuit protection (or current limiting) to prevent misalignment or accidental shorting of the power supply pins from damaging the power supply or hot-pluggable subsystem. Short-circuit protection differs from inrush current protection in that short-circuit protection must distinguish from a transient short-circuit type load (virtual AC short circuit) that is produced by the large input capacitors of hot-pluggable subsystem power supplies or bypass capacitors. The pass device used in a hot-pluggable power supply can fail or be degraded in operating characteristics and reliability if a short circuit is placed across the output terminals of a hot-pluggable power supply.

Typically, implementation of short-circuit discrimination vs. current limiting requires additional complexity within the power supply control circuits and additional components to set operating levels, etc. Large capacitors are required to prevent startup transients from turning on the pass device through the parasitic capacitances of the pass device. Short-circuit protection circuits as well as current limiting circuits are generally desirable with an auto-restart feature so that input power does not have to be removed in order for the hot-pluggable power supply to recover from the protection conditions. Auto-restart circuits typically require external timing components, and due to the long time constants desired, auto-restart circuits typically use large capacitors.

Under-voltage lockout (UVLO) protection is also desirable in hot-pluggable systems, so that the hot-pluggable sub-system power supply does not produce an output until the power supply input has reached a minimum voltage level.

Therefore, it would be desirable to provide an improved method and system for adaptively controlling power supplied to a hot-pluggable subsystem. It would be further desirable to control power supply current during initialization and mechanical contact bounces without requiring additional timing

components, external connections and external components to support operational features. It would be further desirable to provide an auto-restart capability after a short circuit has been detected across a load, without requiring additional components or external circuit connections.

It would additionally be desirable to incorporate UVLO protection and turn-on short-circuit protection without requiring additional external connections. It would further be desirable to provide the above-mentioned features within a small integrated circuit package having a minimum of electrical connections.

SUMMARY OF THE INVENTION

The above objective of adaptively controlling power supplied to a hot-pluggable subsystem is achieved in a method and apparatus. The apparatus includes a pass device for controlling a power supply output and a control circuit coupled to a gate of the pass device. The control circuit controls charging of the gate of the pass transistor in conformity with a detected gate voltage of the pass transistor.

The foregoing and other objectives, features, and advantages of the invention will be apparent from the following, more particular, description of the preferred embodiment of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram depicting a prior art power supply for a hot-pluggable subsystem.

Figure 2 is a schematic diagram depicting a power supply for a hot-pluggable subsystem in accordance with a preferred embodiment of the invention.

Figure 3 is a schematic diagram depicting details of the control electronics of **Figure 2**.

Figure 4 is a pictorial diagram depicting a gate voltage of the pass device during operation of the power supply of **Figure 2**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to **Figure 1**, a prior-art power supply for a hot-pluggable subsystem is depicted. An input supply **12**, provides a source of power for operation of internal components of the power supply and for supplying power to a hot-pluggable subsystem **16**. A pass device **N1**, controls current supplied to **C_{Load}** and thus the power supplied to hot-pluggable subsystem **16**. A control electronics **14** controls the gate of pass device **N1**, so that startup characteristics can be managed. A feedback connection from the drain terminal of pass device **N1** that is coupled to hot-pluggable subsystem **16** is provided to permit control of pass device **N1**. A feedback network formed by capacitor **C2** and resistor **R2** are typically provided to control inrush current, as the charging of **C_{Load}** will be proportional to the current supplied by control electronics **14** to discharge capacitor **C2**. Capacitor **C1** is required to prevent the momentary connection of hot-pluggable sub-system **16** from turning on pass device **N1** via a capacitive voltage divider comprising capacitances **C_{gs}**, **C_{gd}** and **C_{Load}**, since the presence of capacitor **C2** enhances the **C_{gd}** divider effect. Resistor **R2** is added to reduce the effect of the capacitive divider by providing a fixed-frequency impedance in series with capacitor **C2**.

Since capacitances C_{gs} and C_{gd} are relatively small parasitic capacitances associated with pass device **N1** and capacitance C_{Load} is typically very large (generally the input capacitor of a power converter), without the presence of capacitor **C1**, the voltage at the gate of pass device **N1** would initially rise rapidly, causing current to flow through pass device **N1** before the control circuitry has initialized and can drive the gate of pass device **N1** to ground.

Although it is mentioned above that C_{gd} is relatively small, the total gate capacitance of some power metal oxide semiconductor field effect transistors (MOSFETs) is on the order of 1000 picofarads. In order for the power supply of **Figure 1** to operate properly, capacitor **C1** must be made quite large (on the order of 0.1 microfarad for larger pass devices) to prevent conduction of pass device **N1** during the startup transient. Also, capacitor **C2** which may have a value on the order of nanofarads must withstand the voltage difference between the output of the hot-swap power supply (typically -48V) and ground. The capacitors required to implement the prior art circuit are too large for practical inclusion within a power control integrated circuit, and therefore an external terminal for connection of external components is necessary.

Undervoltage and overvoltage protection are provided in the prior art circuit of **Figure 1** by a resistor ladder formed by a resistor **R3**, a resistor **R4** and a resistor **R5**. The junction of resistor **R3** and resistor **R4** is coupled to an undervoltage control input of control electronics **14**. The junction of resistor **R4** and resistor **R5** is coupled to an overvoltage protection input. A window comparator (with hysteresis to eliminate ringing around the trigger point) or other suitable circuit can be used to determine whether or not an overvoltage or undervoltage condition exists by comparing the undervoltage and overvoltage inputs to a reference voltage within control electronics **14**.

Short-circuit protection and current limiting of input supply **12** and pass device **N1** is provided by control electronics **14**. Short-circuit protection typically is provided by a current sense resistor **R1** which provides a voltage to control electronics **14** that is proportional to the current passing through pass element **N1**. If the load is shorted during turn-on of pass device **N1**, the voltage across sense resistor **R1** rises quickly causing control electronics **14** to quickly turn off pass element **N1** before pass element **N1** can be damaged. Control electronics **14** must distinguish between normal in-rush current cause by a large load capacitance and a startup short-circuit

current condition in order to prevent the hot-swap connection from activating the short-circuit protection within control electronics **14**.

Auto-restart circuitry is implemented in the prior art circuit of **Figure 1** by a one-shot circuit comprising resistors **R6** and **R7**, a capacitor **C3**, a transistor **Q1** and a transistor **N2**. When a short-circuit or over-limit current condition is detected via sense resistor **R1**, the gate of pass device **N1** is pulled low, turning off transistor **N2**. Once transistor **N2** is turned off, capacitor **C3** charges exponentially through resistor **R6** and resistor **R7**. The displacement current through capacitor **C3** causes a voltage drop across resistor **R7**, turning on transistor **Q1**. Therefore, while capacitor **C3** is charging, the over-voltage set input of control electronics **14** is pulled low, effectively holding control electronics **14** in a reset condition. When capacitor **C3** is charged almost completely, the current through resistor **R7** falls below the threshold V_{be} of transistor **Q1** and the over-voltage set input rises to its nominal value without the connection of transistor **Q1**.

Since the output of input supply **12** is still within proper range for operation of the prior art hot swap power supply, the control electronics will restart operation. When operation is

restarted, pass device **N1** will turn on until the voltage across sense resistor **R1** again exceeds a threshold.

Referring now to **Figure 2**, a power supply for a hot-pluggable subsystem in accordance with a preferred embodiment of the invention is depicted. While the illustrative embodiment depicted in the drawings and the following description is directed toward a negative voltage power supply having an N-channel pass device in the return path, one of ordinary skill in the art will understand that the techniques and apparatus described herein can be adapted to other types of power supply without undue experimentation. For example, the techniques of the present invention may be adapted to a positive voltage power supply, a power supply having a pass device in the ground path, or a power supply having a p-channel pass device by re-arranging the polarity of operation of the control electronics and types of pass element.

It should be noted for the embodiments of the present invention as depicted in the following figures, that the pass device and control electronics may be incorporated within a host system or a hot pluggable system or both. For example, in a Powered Ethernet environment, it is useful to provide a hot-pluggable power control device within the host system to provide

short-circuit protection and other features such as contact debounce and inrush current control, while also providing a second power control device within the hot-pluggable subsystem itself. This second power control device is used to "hold off" current drain or any load impedance for a time period during startup, since the Powered Ethernet specification requires "discovery" of a specific impedance signature before turn on and before a hot swapping function may occur. Typically these functions are provided by circuits designed to perform the particular tasks required on each side of the hot-pluggable subsystem connector, but as will be illustrated for the embodiments of the present invention, an integrated circuit performing functions required on each side of the connector can be an identical device, wherein differing portions of the full functionality of the device are utilized on the different sides of the connector.

Referring again to **Figure 2**, an input supply **22**, provides a source of power for operation of internal components of the power supply and for supplying power to a hot-pluggable subsystem **26**. A pass device **N10**, controls power supplied to a hot-pluggable subsystem **26**. Pass device **N10** may be a MOSFET, JFET, GAsFET, Germanium FET, IGBT or other suitable control device having an essentially capacitive gate characteristic. A

control electronics **24** controls the gate of pass device **N10**, so that startup characteristics can be managed.

Control electronics **24** may be coupled to input supply **22** through an optional zener diode **D1**. Zener diode **D1** may be a string of diodes, a voltage regulator, zener diode or other device that permits setting the input supply voltage terminal to a voltage other than that of the output of input supply **22**. Since control electronics **24** contains an internal voltage sensing circuit that determines the under-voltage lockout voltage level, the undervoltage lockout level may be programmed through the use of an external device such as zener diode **D1**. If zener diode **D1** or other device is not used, the input power supply terminal of control electronics **24** is coupled directly to the output of input supply **22** and control electronics **24** will use its own internal under-voltage lockout level. As an example, if the output of input power supply **22** is -48V and optional zener diode has a breakdown voltage of 27V and the internal under-voltage lockout threshold is 8V, the startup voltage for control electronics **24** will be 35V. In this manner, the internal under-voltage lockout level may be set to the minimum voltage required for control electronics **24** to operate and properly control the gate of pass device **N10**. Since this voltage is

generally very low compared to the input power supply **22** output voltage, a wide range of startup voltages may be programmed.

In the preferred embodiment of the present invention, a feedback connection from the drain terminal, which is coupled to hot-pluggable subsystem **26**, is not required to control pass device **N10** during startup, since the rate of voltage rise of the gate of pass device **N10** may be set within control electronics **24** and thus within an integrated circuit containing the hot-swap power supply. Therefore, a three-terminal power control device may be implemented in accordance with embodiment of the present invention that either incorporates pass device **N10** internally or connects pass device **N10** externally.

Without the techniques of the present invention, a power control device having an external pass element and including inrush protection and startup short circuit protection having only three terminals is not possible and current must be sensed externally. If pass device **N10** is incorporated internally, its drain terminal becomes the third terminal (rather than the gate terminal) and current can be sensed through a current mirror from the on board pass device.

The present invention reduces interconnect requirements and the need for a large external capacitor by using a novel mechanism to measure the operation of pass device **N10**. Rather than typical feedback provided from the drain-gate connection, the present invention determines characteristics of pass device **N10** by detecting a gate voltage of pass device **N10**.

Control electronics **24**, pass device **N10**, and any other associated components forming a hot-pluggable power supply can be incorporated within a host system, a hot-pluggable subsystem or both. As illustrated in the above-disclosed example for powered ethernet, a hot-pluggable power supply can be incorporated in a host system to perform some functions and within a hot-pluggable subsystem to perform other functions.

Referring now to **Figure 3**, details of the control electronics of **Figure 2** are depicted. A regulator **32** provides internal regulated power for the control electronics. Current source **I₀** and capacitor **C10** provide a ramp generator that is coupled to the non-inverting input of an amplifier **A1**. Amplifier **A1** is a common-mode feedback circuit having a low difference mode gain. Amplifier **A1** sets the common-mode operating voltage that is coupled to capacitors **C22** and **C23**. The inverting input of amplifier **A1** is coupled to the **gate** terminal of control

electronics **24**, providing a feedback path from the gate of pass device **N10**. Amplifier **A1** has an inverting output coupled to capacitor **C22** through switch **S1** and a non-inverting output coupled to capacitor **C23** through switch **S1**, so that when switch **S1** is closed, the voltages on capacitors **C22** and **C23** have a difference that represents the loop error controlling the voltage on the **gate** terminal. When switch **S1** is open, the above-described circuit acts to cancel leakage through capacitors **C22** and **C23**, which is critical to circuits where capacitors **C22** and **C23** are integrated circuit capacitors. Since capacitors **C22** and **C23** can be made as interwoven capacitors within a "sea" of matched unit devices, their leakage is closely matched, providing a differential hold signal that is stable after switch **S1** is opened.

The difference between the voltage on capacitor **C22** and the voltage on capacitor **C23** is sensed by a transconductor formed by transistors **N15**, **N16**, **P13**, **P14** and current sources **I₅**, **I₆**, **I₇**, and **I₈**. N-channel FETs **N15** and **N16** are matched, as are P-channel FETS **P13** and **P14**. Current sources **I₅** and **I₇** are of equal magnitudes, as are currents **I₆** and **I₈**. The above conditions provide a transconductor that will match the voltage of the ramp generator implemented by current source **I₀** and capacitor **C10**, with the voltage at terminal **gate**, which is provided for connection to

the gate of pass device **N10** of **Figure 2**, by controlling the magnitude of the gate current flowing into the gate of pass device **N10** of **Figure 2**. Other circuits, such as operational transconductance amplifiers or voltage-current converters may be used to produce a similar result as produced by the transconductor used in the preferred embodiment of the present invention.

The drain of transistor **P14** is coupled to the gate of transistor **N13**, which in turn controls a current mirror **M1** having an output coupled to the **gate** terminal. Current mirror **M1** controls the current flowing into the gate of pass device **N10** of **Figure 2**. Assuming that the **gate** output is initially low, the voltage on the gate of transistor **P14** will cause a voltage drop across resistor **R10** which is coupled from the source of transistor **P14** to the source of transistor **P13**. The resulting current through resistor **R10** flows into the drain of transistor **N16**, generating a voltage from the source to drain of transistor **P14**, which is coupled to the gate of transistor **N13**. Transistor **N13** has characteristics that are matched with the characteristics of transistor **N16**. Therefore the current flowing through **N16** is mirrored at the input of current mirror **M1** by transistor **N13**.

Current mirror **M1** forces a current into the gate of a pass element coupled to the **gate** terminal (such as pass device **N10** of **Figure 2**) thus producing a closed loop. The time constant of the loop is set to permit the current charging the gate of a pass device to produce a voltage which matches the ramp voltage produced across capacitor **C10** by the time a voltage of **V_{L2}** (which is set at 1V or another suitable voltage less than the typical threshold voltage of pass elements that might be used with the circuit) is reached on the **gate** terminal. The loop acts to equalize the voltage on the gate of transistor **P13** and the voltage on the gate of transistor **P14** by changing the voltage on the gate of transistor **N13**, otherwise the current produced through resistor **R10** is zero and no change occurs in the voltage of the gate of transistor **N13**.

Before the threshold voltage of pass device **N10** of **Figure 2** is reached, a comparator **K2** detects that the ramp generator voltage has reached the threshold voltage **V_{L2}**. The output of comparator **K2** is coupled to switch logic **34** and switch logic **34** opens switch **S1** in response to comparator **K2** detecting that the ramp generator voltage has reached the threshold voltage **V_{L2}**. A capacitor **C22** and a capacitor **C23** are coupled to outputs of switch **S1** and to the transconductor formed by transistors **N15**, **N16**, **P13**, **P14** and current sources **I₅, I₆, I₇, and I₈**.

The voltage on the gate of transistor **N13** is held constant by the transconductor, since the voltage difference across capacitors **C22** and **C23** is constant. Any leakage from capacitors **C22** and **C23** will be equal and therefore will not affect the voltage difference. The differential voltage across capacitors **C22** and **C23** is the voltage required to cause the transconductor to produce a voltage on the gate of transistor **N13** that maintains the charging rate of the gate of pass device **N10** of **Figure 2** to match the voltage across ramp generator capacitor **C10**. In this manner, the charging current is normalized to match the rate of change of the ramp generator output, creating a consistent ramp profile independent of the device characteristics of pass device **N10** of **Figure 2**. Additionally, the operation of the circuit overcomes leakage that might cause a non-adaptive scheme to never turn on. Thermal compensation, pass device size and pass device characteristic compensation are provided to a first order approximation.

If pass device **N10** of **Figure 2** is incorporated within a power control integrated circuit that contains control electronics **24**, a current mirror transistor may be added having a threshold voltage matched to the threshold voltage of pass device **N10** of **Figure 2**. The current mirror transistor has a gate

coupled to the gate of pass device **N10** and generates a much smaller current that is proportional to the current through the channel of pass device **N10**, providing a reference current that may be used to detect current levels for turn-on short circuit protection and operating short circuit protection. The reference current may also be used to scale charging current I_0 providing a ramp that is scaled to the characteristics of pass device **N10**. This reference mirror effectively detects the gate voltage of pass device **N10** and provides control in conformity with the gate voltage by creating a scaled current proportional to the gate voltage of pass device **N10**.

Referring now to **Figure 4**, the novel operation of the present invention is depicted by showing a unique gate voltage characteristic associated with the operation of the circuits of **Figure 2** and **Figure 3**. From time t_0 until time t_1 , the gate voltage of pass device **N10** of **Figure 2** is held at ground potential due to the operation of a power-on-reset delay and/or an under-voltage lockout condition during which the charging of capacitor **C10** is held off. At time t_1 current source I_0 begins charging capacitor **C10**. At time t_2 , comparator **K2** detects that the ramp voltage has crossed the threshold level V_{L2} and the sample-hold action of switch **S1** and capacitors **C22** and **C23** holds the gate charging current constant at a rate required to match

the ramp across capacitor **C10** by maintaining a constant voltage on the gate of transistor **N13**. At time **t₃**, the threshold voltage of pass device **N10** of **Figure 2** is reached and the Miller effect causes the parasitic **C_{gd}** of pass device **N10** to be multiplied by the gain of pass device **N10**. This increase in effective capacitance causes the voltage ramp at the gate of pass device **N10** to change from the steep characteristic seen from the time period from **t₁** to **t₃** to an almost unchanging voltage characteristic. This unchanging characteristic continues until the load capacitance **C_{Load}** of hot pluggable subsystem **25** has fully charged at **t₄** when the drain voltage of pass device **N10** of **Figure 2** stops changing and the effective capacitance of the gate of pass device **N10** returns to its nominal value without the Miller effect. From time **t₄** to time **t₅** the rate of change of the gate voltage of pass device **N10** again increases until the gate voltage reaches the full value produced at the **gate** terminal of control electronics **24**.

In contrast to the above-described circuit operation, if a short-circuit condition exists across load capacitance **C_{Load}**, the drain of pass device **N10** of **Figure 2** will not change and the Miller effect will not occur. Therefore, the gate voltage of **N10** will continue to rise at the previously adapted rate (the rate of rise from **t₁** to **t₃**) as noted by the dashed line labeled "short

circuit load condition." A short-circuit detector is implemented by comparator **K1**, which has a threshold voltage **V_{L1}**. A short-circuit condition is detected if comparator **K1** switches before time **t₄**. The reference voltage input **V_{L1}** is determined by empirical tests of standard pass elements. In response to detecting a short-circuit startup condition, switch logic **34** may restart operation by discharging capacitor **C10** through a switch **S2** and discharging the gate of pass device **N10** of **Figure 2** through transistor **N14**, resetting the hot-swap controller. Switch logic then delays the restart operation using an internal timer which is generally a timer having a period longer than the power-on reset delay. The circuit would again begin operation from time **t₀** and the above-described behavior will repeat until the short-circuit condition is removed. As the operation of control electronics **24** is scaled to the characteristics of pass device **N10** of **Figure 2**, the timings and voltages are normalized irrespective of pass device **N10** of **Figure 2** characteristics, thereby providing short circuit protection without measuring the current through pass device **N10**.

It should be noted that the above-described circuit detects short-circuit conditions that exist during startup of the power supply. Short-circuit conditions that occur subsequent to insertion and startup may be detected by a voltage change

detector **38** coupled to the gate of the pass device. A short-circuit that suddenly occurs either due to a failure of the hot-swappable subsystem or due to misconnection such as might occur during extraction of the hot-swappable subsystem will cause a sudden change in the voltage at terminal **gate**, due to the parasitic capacitance between the gate and drain of pass device **N10** of **Figure 2**. Voltage change detector **38** then signals switch logic **34** to restart or shut down operation of the power supply.

One or more counters may be maintained within switch logic **34** to limit the number of retries attempted at startup or detection of short-circuit conditions. Switch **S2** may also be controlled by other logic within switch logic **34** to provide an initial delay for providing a power-on-reset interval and further by a voltage sensing circuit **36** coupled to the power supply input voltage to provide under-voltage lockout protection. As described above in the text accompanying **Figure 2**, the under-voltage lockout level may be programmed by inserting a zener diode or other device in series with the power supply input to the hot-swap power supply.

A novel circuit may be used to circumvent the initial transient feed-through that occurs when a load is connected to the hot swap power supply. The capacitive ladder formed by **C_{gs}**

, C_{gd} and C_{Load} turns on **N10** of **Figure 2** in the absence of circuitry controlling the gate voltage, which happens during the startup of a hot-swap power supply. A transistor **N14** provides a path to ground for charge appearing at the gate of pass device **N10**. Since transistor **N14** is a depletion MOSFET, until V_{L3} reaches a voltage higher than the voltage at the **gate** terminal plus V_{po} (the pinch-off voltage of transistor **N14**), transistor **N14** will conduct, drawing the gate of pass device **N10** to ground.

Reference voltage V_{L3} is coupled to an internal reference such as an internal regulator output. As reference voltage V_{L3} rises, transistor **N14** will begin to turn off and when reference voltage V_{L3} reaches $V_{dd} + V_{po}$, transistor **N14** will be turned completely off. Transistor **N14** will be held in an off state permanently unless the input voltage to the hot-swap power supply falls too low. A resistor **R11** is coupled to the gate of transistor **N14** so that the gate voltage is maintained at ground potential until the reference circuit producing V_{L3} has reached a stable voltage. Alternative circuits may be used to clamp the **gate** terminal such as a bipolar transistor or a darlington pair coupled to the **gate** terminal with a base connected to an internal voltage reference that is available as the input voltage rises. The bipolar transistors are then disabled once the control electronics **24** circuits become operational. The depletion mode transistor **N14** implementation is preferred since it will conduct at startup and

continue to conduct until the circuits within control electronics **24** become operational.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form, and details may be made therein without departing from the spirit and scope of the invention.

U.S. GOVERNMENT PRINTING OFFICE: 1944 10-1200